Report No. 2-32300/3R-53434
Contract NAS8-34678
9 May 1983

Development of Deployable Structures for Large Space Platform Systems

Volume 1

Executive Summary

Prepared for:

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Alabama

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By:

Vought Corporation
Dallas, Texas

LTV Vought

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EXECUTIVE SUMMARY

PREPARED FOR:
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FOREWORD

This volume summarizes an 18 month study of deployable structures for large space platform systems. The study was conducted by the Vought Corporation for the NASA George C. Marshall Space Flight Center. The work was performed under contract NAS8-34678 in two parts. Part 1 spanned the period 29 October 1981 through 31 July 1982; Part 2 covered the period 9 August 1982 through 9 May 1983. The effort was monitored by Erich E. Engler, COR, and W. E. Cobb, Co-COR of the Structures and Propulsion Laboratory. Dr. R. L. Cox of Vought was Study Manager of the program. Mr. R. A. Nelson performed conceptual and design studies and coordinated design effort. Mr. H. C. Allsup conducted interface design studies and deployable volume integration studies. Mr. G. M. Richards conducted design studies for the ground test article. Messrs J. B. Rogers, R. W. Simon, J. J. Atkins and J. R. Hyden performed structural analyses. Mr. C. A. Ford and P. Y. Shih conducted dynamic analyses. Mr. D. D. Stalmach carried out thermal and deployability analyses. Mr. J. A. Oren performed new technology and cost studies and directed thermal analyses. Materials studies were conducted by Mr. G. Bourland and Mr. M. W. Reed. Mr. G. L. Zummer performed studies for manufacturability. Mr. R. E. McPartland provided electrical design support.

The authors wish to thank the contributors mentioned above for their dedication and for the excellence of their support to this program. The authors also wish to thank Messrs Engler and Cobb for their guidance and support during this study, and Mr. J. J. Pacey of Vought for his valuable consultation and assistance. Special thanks is due to Ms. D. M. Fethkenher who provided secretarial, data management and publication services throughout the program.

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1.0 INTRODUCTION

Studies of future space applications show an emerging need for multipurpose space platform systems. Prior work has focused on the development of generic structural platforms and on point designs of systems for a few missions such as geostationary communications and scientific experiments. In order for the user community to realize the potential benefits of large structures for early 1990's missions it is important now to develop and demonstrate platform systems which offer both a high degree of versatility and which effectively integrate requirements for utilities, subsystems, and payloads. In addition, future missions such as a Space Station will require both pressurized and unpressurized volumes for crew quarters, manned laboratories, inter-connecting tunnels, and maintenance hangars. To minimize launch costs and enable use of volumes greater than those which can be transported by the Space Shuttle Orbiter, it is also desirable to evolve deployable volume concepts.

The current 18 month program was carried out in two parts. Part 1 involved the review, generation, and trade of candidate deployable linear platform system concepts suitable for development to technology readiness by 1986, with the selection of one of these concepts for further design and evaluation during Part 2; and the generation and screening of candidate concepts for deployable volumes. The systems concepts were based on trades of alternate deployable/retractable structure concepts, integration of utilities, and interface approaches for docking and assembly of payloads and subsystems. The Part 1 deployable volume studies involved generation of concepts for deployable volumes which could be used as unpressurized or pressurized hangars, habitats and interconnecting tunnels. Concept generation emphasized using flexible materials and deployable truss structure technology. Promising concepts were selected for continued Part 2 evaluation.

Part 2 involved layout design of a ground test article based on the results of the concept selection from Part 1. The design was to meet the specification for a prior NASA-MSFC ground test article simulating a Science and Applications Space Platform (SASP) arm. An aluminum structure design was derived from the Part 1 graphite/epoxy flight article conceptual design. Deployable volume effort during Part 2 focused on evolving the selected Part 1 truss/bladder concept for the habitat and hangar modules. Included were selecting a specific truss concept for the habitat and hangar, minimizing the requirements for EVA during buildup, maintaining large deployed/stowed volume ratios, and conducting more detailed evaluations of crew accommodations, design characteristics, and Orbiter/Space Station compatibility. Single concepts for the habitat and hangar were selected and characterized.

2.0 DEPLOYABLE PLATFORM

The elements of a deployable platform system are illustrated in Figure 1, adapted from the Definition Study of the Advanced Science and Applications Space Platform (ASASP). The core element of the deployable platform system is its automatic deployable/retractable structure. Some of the major interfaces are the spacecraft utilities, where full integration with the structure is desired, subsystems and payloads, docking, assembly, EVA, and various joints and attachments. All aspects of the interfaces are important influences to the deployable platform system design, including physical characteristics, imposed loads, dynamic interactions between the structure and attitude control subsystems, thermal distortion, payload stability requirements and deployment/assembly operations.

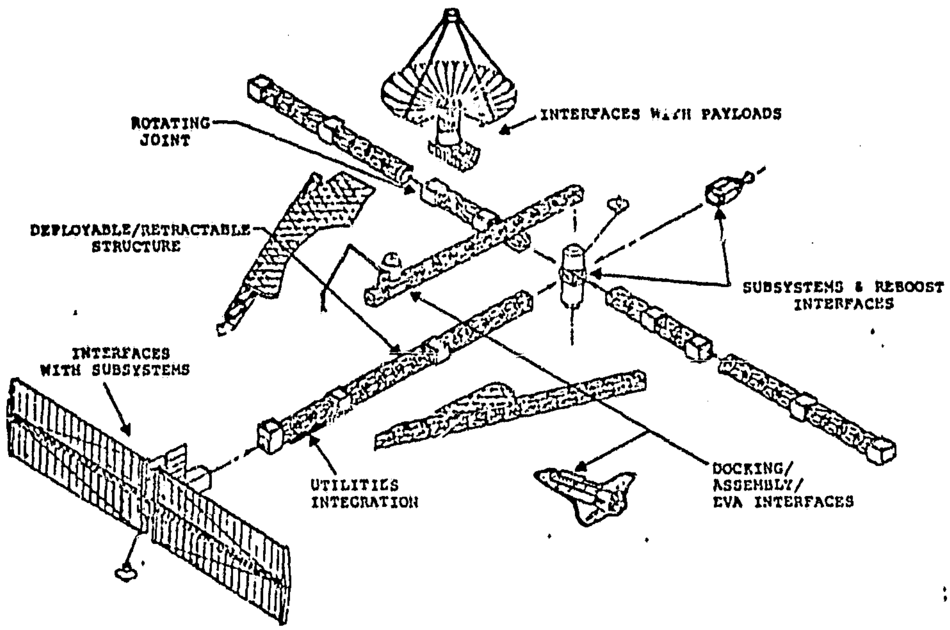

FIGURE 1 ELEMENTS OF DEPLOYABLE PLATFORM SYSTEM

2.1 Platform Requirements

The platform concepts are based on generic system requirements and selection critieria consistent with three focus missions:

Advanced Science and Applications Platform (ASASP)
Geostationary Communications Platform (GSP)
Solar Power Satellite Test Article II (SPS TA II)

Four of the major areas in which requirements were determined included stiffness of the deployable truss structure, strength, utilities to be integrated into the truss structure, and interfaces. A parametric evaluation of stiffness requirements showed that beam bending stiffness values in the range 10^6 to 10^7 Nm^2 are required for small beams with a truss width of about 0.5 m. Stiffness requirements increase with beam size, reaching values

in the range 10^8 to 10^9 Nm^2 for larger beams of 3 to 4 m width. Strength requirements for beams were also identified parametrically, and range from 10^3 to 10^4 Nm for the smaller beams up to about 10^5 Nm for large beams. Utility integration requirements range from a utility cross-sectional area of approximately 5 cm^2 for small trusses up to about 70 cm^2 for truss widths of 3 to 4 m. Four generic types of interfaces were identified: truss-to-truss interfaces, truss-to-module interfaces, docking/joining interfaces, and truss-to-equipment/payload interfaces.

2.2 Design Issues

The first major issue was truss folding. The alternatives considered were single vs double fold. The approach adopted was double fold because of the importance of volume ratio and packing efficiency. It was also established that a truss configuration with a versatility for either folding capability would be preferable. The second major issue was utilities integration. The alternatives considered were fully integrated utilities with the bundles either internal or external to the struts (but routed adjacent to the struts), or partially integrated with reels or trays internal or external to the truss lattice. The approach adopted was to design for fully integrated utilities. However it was also desired to provide compatibility for attachment of strap-on utilities for "tall pole" missions. The third major design issue was payload integration. The alternatives considered were integration by a payload interface module vs payload interface directly to the truss. Because each of these alternatives have distinct advantages in certain design situations, the approach was to accommodate both. The fourth major issue was that of subsystem integration. The alternatives considered were integration by subsystem module vs integration directly onto the structure. Again there are advantages to either, and the approach chosen was to accommodate both alternatives. The fifth design issue was modularity, where the alternatives were a fully modular structure consisting of standarized building blocks vs a modular/scalable structure which had a standard scalable design. The chosen approach was to design for the modular/scaleable structure but not to preclude use as standard building blocks where this would be beneficial.

2.3 Concept Trades and Selection

Conduct of the deployable platform systems study was initiated with the structural concept generation and evaluation effort. A large number of potential deployable truss candidates were identified and judgementally evaluated against Level 0 criteria and screened to eleven candidates, pictured in Figure 2. A more detailed evaluation and screening procedure was applied to the eleven. That resulted in a selection of four candidates, also shown in Figure 2. These were the Biaxial Double Fold (BADF), the Double Fold (DF), the Square Diamond Beam Truss (GDC), and the Box Truss (MMC). Each of these package compactly, offer good potential for automatic deployment/retraction and utilities integration, and have promise of versatility of application.

The next step of the deployable platform study was to conduct design and analytical trades on the four surviving truss concepts. These entailed design studies of utilities, subsystem and payload integration, and branching/assembly interfaces for evaluation of versatility for assembling deployed modules. Parametric, structural, and thermal analyses were performed to support the trades and a materials selection study was conducted with the result that all structural sizing was carried out on a high modulus

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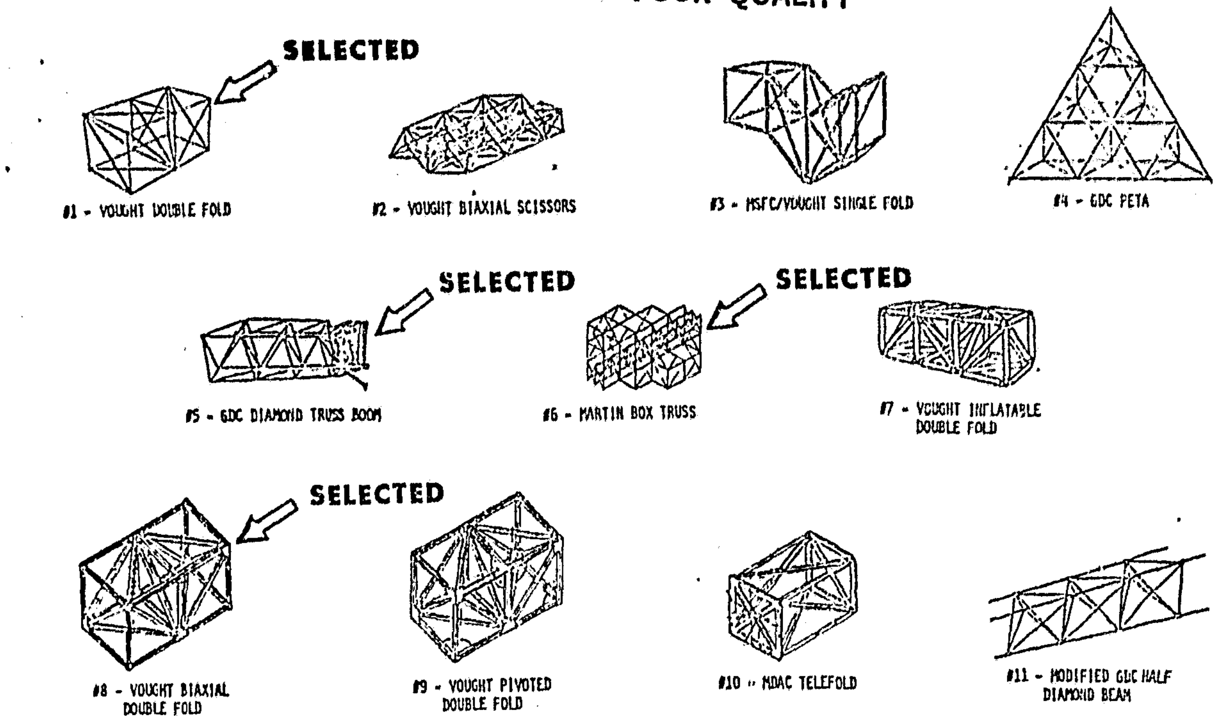

FIGURE 2 STRUCTURAL CONCEPTS EVALUATED

graphite/epoxy composite (GY70/934). Cost trades, which identified differences due to both fabrication and Shuttle launch, were also conducted . Based on the trade results each of the four deployable truss concepts was scored against 26 individual criteria relating to five major categories; platform capability, deployability, versatility, integration, and performance. Weighting factors were assigned and a final ranking was determined. The Biaxial Double Fold was clearly superior in each major category, and was thus selected for further definition during Part 2.

2.4 Selected Platform Concept Description

An overview of the characteristics and capabilities of the selected BADF concept is given by Figures 3 through 9. The general arrangement of a 3 meter square beam with utilities integrated inside the struts is summarized in Figure 3. The sketch also illustrates the folding scheme of the BADF. The truss folds simultaneously in two directions by telescoping the vertical struts and pivoting the bulkhead and side diagonals. All cells in the truss fold at the same time. This folding scheme minimizes the number of joints and the stowage volume. It results in a packaged height equal to diagonal length. Only two types of nodes are involved in the BADF concept; "A" nodes to which all diagonal struts are attached, and "B" nodes. Figure 3 also indicates the method used to energize the deployment and retraction. Deployment is by a combination of energy stored in linear springs located in the vertical struts and coil springs in bending located in the longitudinals and the laterals at the A nodes. Tension on the cable system provides the force for retraction and also an opposing force for control during deployment. A single reversible cable drive motor actuates the entire deployable truss. The figure also indicates the utilities integration

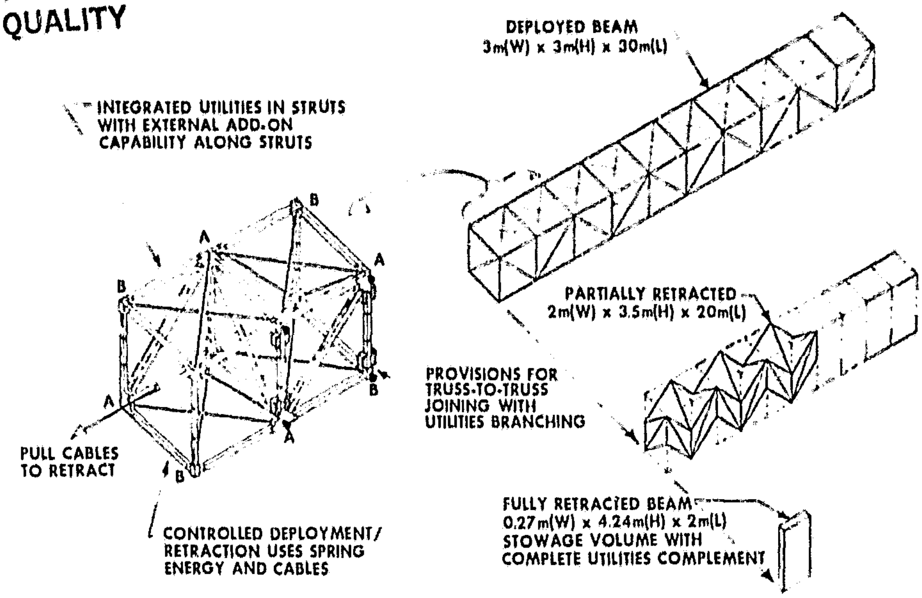

FIGURE 3 FEATURES OF SELECTED BADF STRUCTURE

approach, where a full complement of utilities for a large deployable platform such as the ASASP can be routed through the hollow longitudinal struts. Additional space is available for an equal quantity of add-on utilities mounted external to the longitudinal struts should that be desirable for some subsequent missions. Provisions for utilities and mechanical connectors, which will be necessary for branching of truss sections and payload interfaces, are located on the sides or end of a truss section. Figure 4 shows photographs of a model fabricated by Vought, approximately 1/10th scale relative to a 3 m beam. The photographs show the model in its fully retracted condition, followed by views in partial and full deployment. The deployed dimensions of the model are 112 cm in length and 28 cm square. The model is constructed of brass. The cable system for control and retraction is made from nylon fishing cable for the model.

Figure 5 shows how the Biaxial Double Fold truss may be used as an area platform. Illustrated is a square platform consisting of 10 rows and columns of cells, with overall dimensions of 25.9 m x 25.9 m x 2.6m. The diameter of the struts for this illustration is 5 cm. The retracted dimensions are 1.3 m x 1.3 m x 3.6 m.

Figure 6 summarizes the utility integration and interface concept. The concept for routing of utilities through nodes is illustrated by the B node design sketched in the figure. The bundle bend radius-to-diameter ratio shown is about unity. This value was found to be acceptable from our element tests for both bending moment and cycle life. The interface concept at a B node shows how utilities are branched from the opposite A node, routed through the bulkhead lateral strut, and then passed under the utility in the B node longitudinal to a floating connector fixed to the vertical strut. The interface concept at the A node is similar, only branching is directly from the A node rather than through a crossover from the opposite side of the truss.

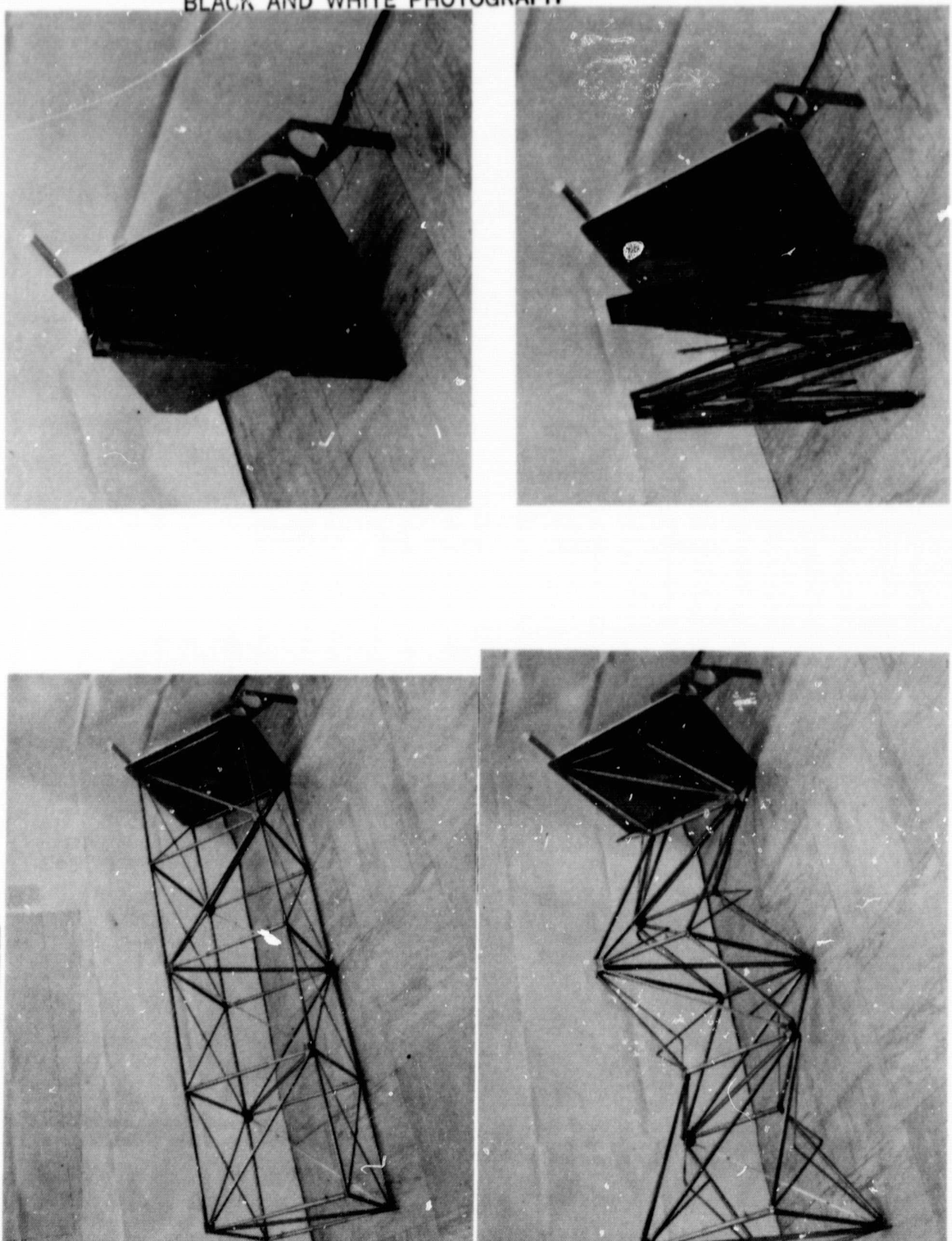

FIGURE 4 BIAXIAL DOUBLE FOLD TRUSS TENTH SCALE MODEL

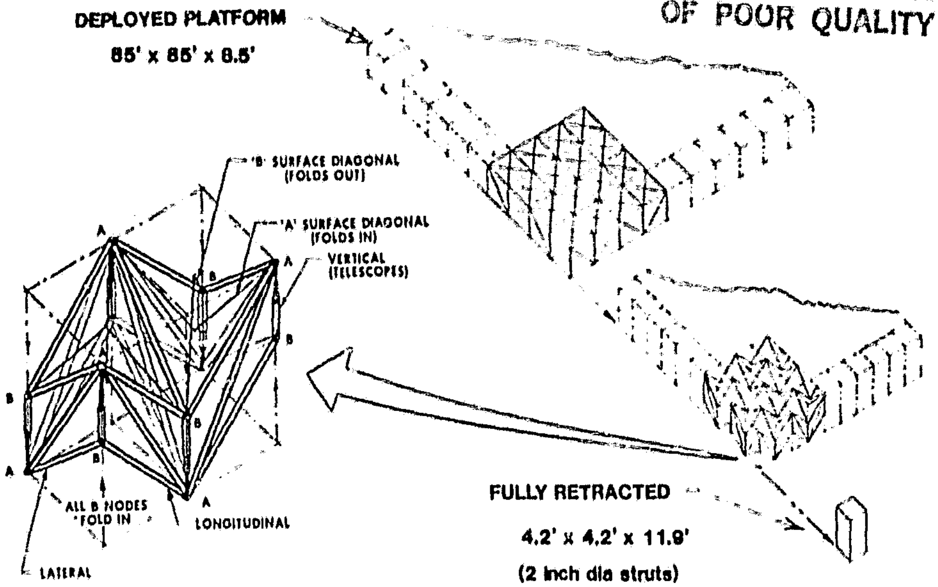

FIGURE 5
BIAXIAL DOUBLE FOLD AS AN AREA PLATFORM

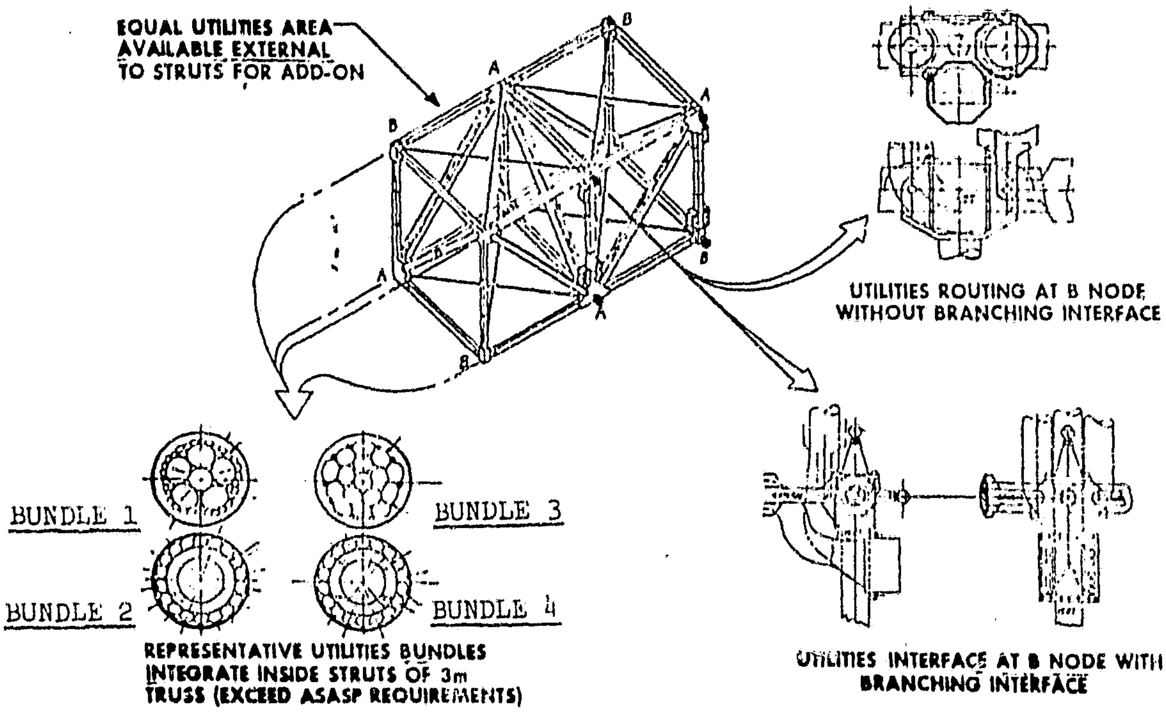

FIGURE 6
UTILITIES INTEGRATION CONCEPT FOR BADF

Figure 7 shows the types of truss-to-truss and truss-to-module interfaces possible. With the interface design described in conjunction with

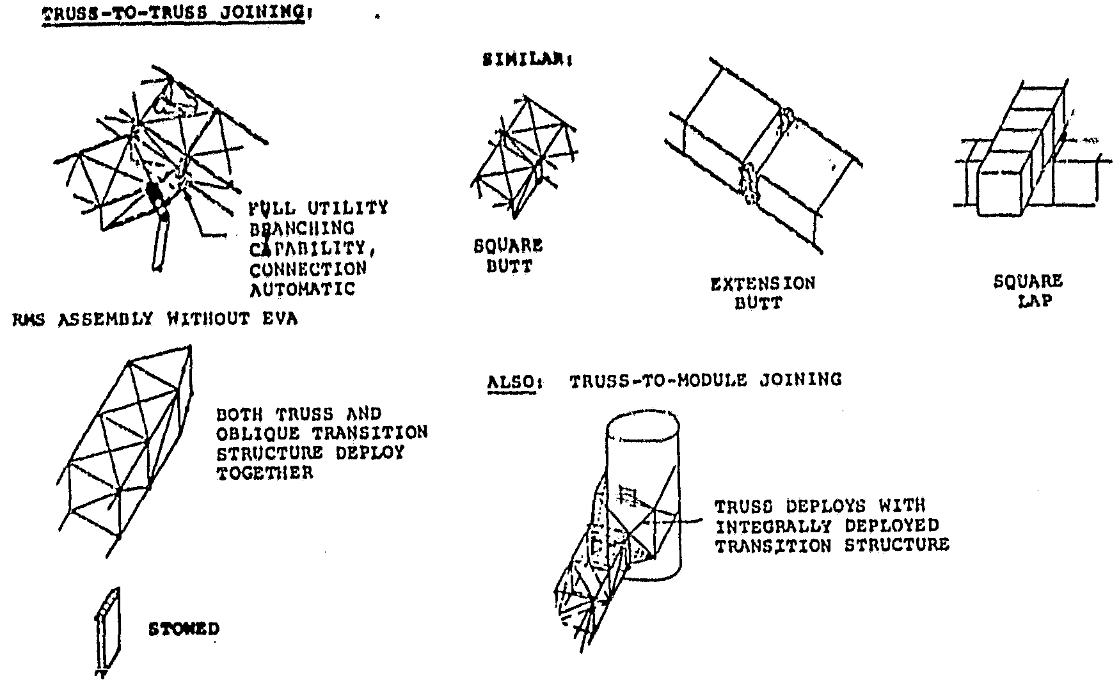

FIGURE 7 MODULE DEPLOYMENT ASSEMBLY WITH BADF

Figure 6, the truss joining is accomplished in two steps. First the truss branches to be joined are maneuvered together using the RMS until capture and hard lock is accomplished at four nodes by the mechanical node-to-node Autolock Coupler. Second, an electrically powered ultility connector plate, not shown, pulls together the connectors with the aid of alignment pins, completing the mating operation. As indicated in Figure 7, various types of square, oblique, and size change interfaces are possible without the addition of separate interface structure. This results from the peculiar capability of biaxially deploying trusses to intregrally deploy oblique or size-change transition structure.

Figure 8 illustrates a mast experiment that can be flown in the Space Shuttle using the BADF design. Illustrated on that figure are the characteristics for a 50 cell, 100 m long redeployable mast packaged in the Space Shuttle. The packaging requirements are also indicated. One advantage of the folding characteristics for the BADF are that it can be stowed in a 1 m length in the Shuttle cargo bay. This short stowage dimension provides advantage in the manifesting of a Shuttle flight.

2.5 Ground Test Article Design

Figure 9 is an isometric sketch illustrating the BADF ground test article design features. The test article interfaces the existing NASA air bearing facility for zero-g simulation. It also interfaces the existing base structure. The overall length of the ground test article is about 14 m. There are 10 cells, each about 1.4 m square. The material of construction was

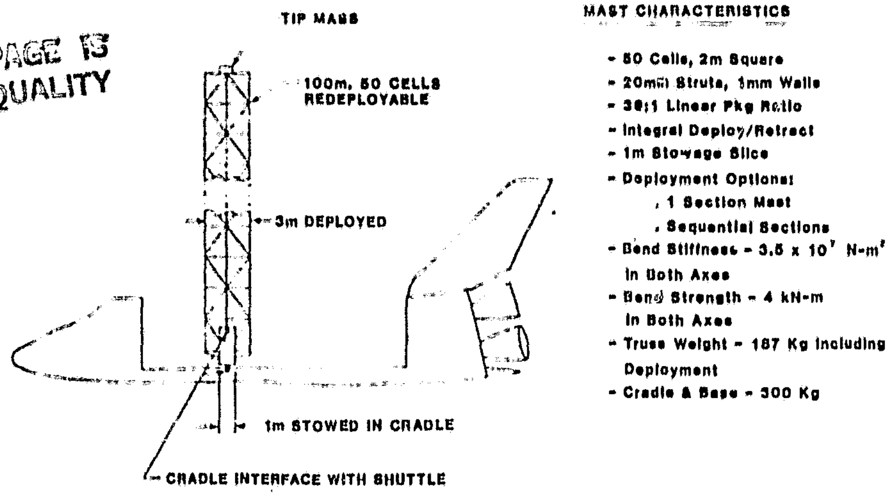

FIGURE 8
BADF MAST EXPERIMENT

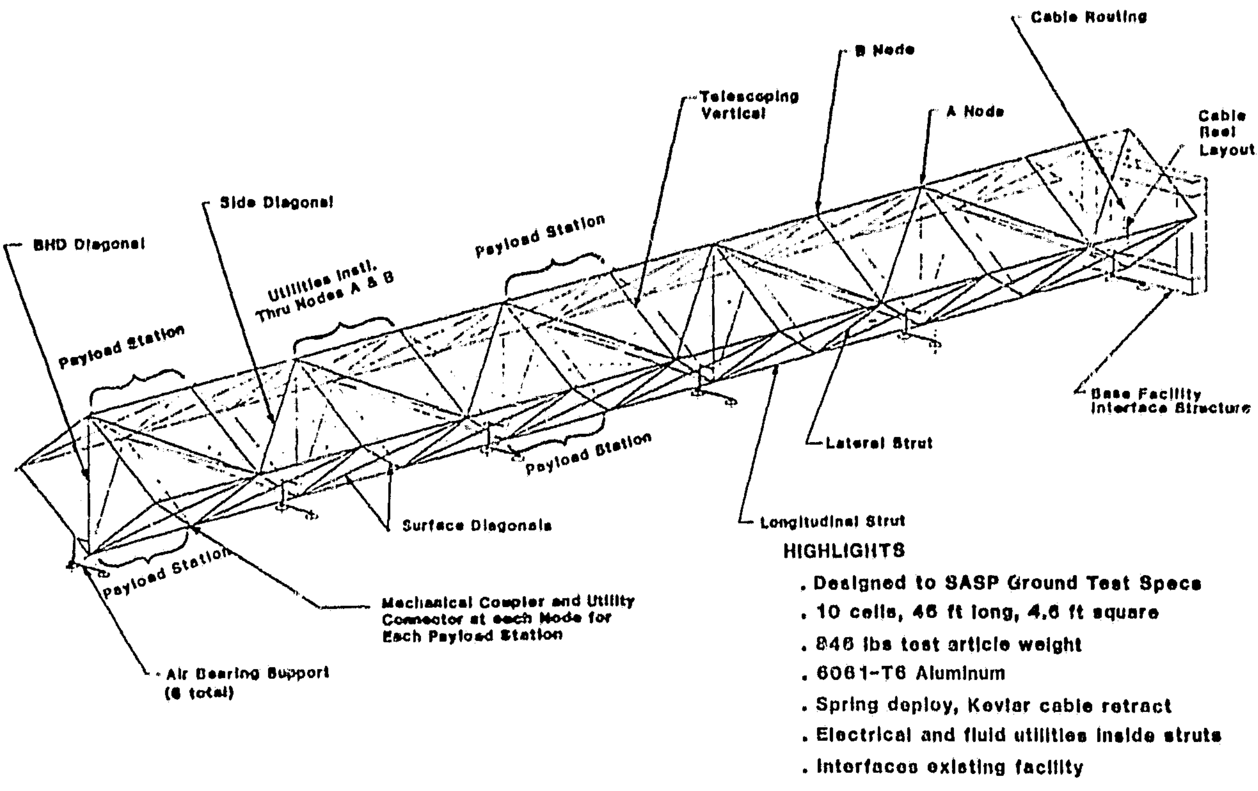

FIGURE 9
SUMMARY OF PART 2 BADF GROUND TEST DESIGN

specified as aluminum, our design uses the 6061-T6 alloy, and Kevlar-29 for the cables. There are four stations capable of supporting a 3640 kg payload, each having utility interfaces for both fluid and electrical connections. Six air bearing supports are provided. The test article is oriented on edge for deployment. Subsequent to deployment it may be rotated to other positions to allow determination of characteristics in various orientations. Weight of the 6061-T6 aluminum structure is approximately 384 kg. Figure 10 shows the stowed configuration and launch packaging for the BADF ground test article.

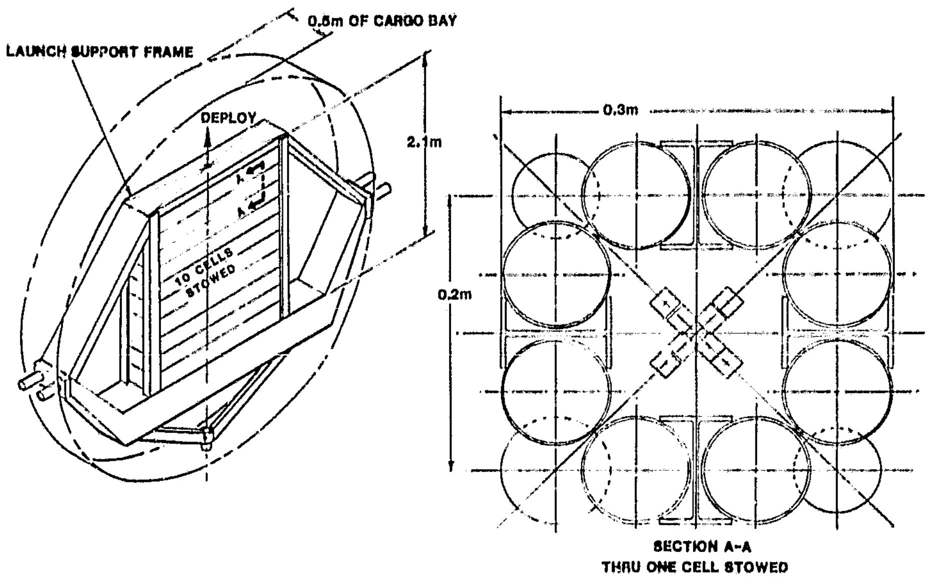

FIGURE 10
STOWED CONFIGURATION AND LAUNCH PACKAGING BADF GROUND TEST DESIGN

The article occupies a length of about 0.5 m in the Shuttle cargo bay when packaged with the support structure. The height of the stack of ten stowed cells is about 2.1 m. The cross section through one cell is shown to be approximately 0.2 m x 0.3 m. While it may be unlikely the ground test article constructed from aluminum would be flown in a flight experiment, similar packaging would be obtained with a composite system. Versatility was also provided in the design of the ground test article to allow neutral bouyancy testing by change of the springs in the vertical struts and addition of flotation chambers.

The ground test article design is also suitable for Orbiter flight test experiments with modifications to increase stiffness at partial deployment to accommodate potential Shuttle accelerations up to 0.04 g. The use of localized deployment motors on B nodes to shorten cable runs, a 50% increase in crossectional area of diagonals, and fabrication of the structure from graphite/epoxy would reduce maximum tip deflections at 70% of deployment to 25 cm.

2.6 Deployable Platform Conclusions

Part 1 Studies:

1. The deployable platform system with fully integrated utilities and subsystem/payload interfaces is feasible.

2. The Biaxial Double Fold truss is the clear choice of four leading candidates.

3. Automatic deployment and retraction in a self-contained system can be achieved.

4. The Biaxial Double Fold design provides typical storage ratios of 172:1 for a 3 m truss with full utilities. Ratios as high as 300:1 are possible with minimal utilities.

5. Utilities integrated inside truss struts with interfaces for branching are possible. Equal space for growth external to struts also exists.

6. Small payloads/subsystems may be preattached locally to the truss. Large items may interface through berthing hardware which may be preattached.

7. Truss-to-truss interfaces and integrally deployed transition structure provide a wide variety of building block configurations.

Part 2 Ground Test Article Design:

1. Layout drawings have been completed for the Biaxial Double Fold ground test article. The article meets all the requirements of the NASA specifications.

2. Simple interfaces have been achieved with existing NASA-MSFC air bearing facility frictionless platform, and a minimum of changes will be required to accommodate the Biaxial Double Fold test article.

3. While the ground test article is designed for testing on an air bearing platform, it is also suitable for modification for neutral bouyancy testing.

4. The basic ground test article is also suitable for Orbiter flight test experiments with some modifications.

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3.0 DEPLOYABLE VOLUMES

Figure 11 shows three potential missions which could utilize the benefits of deployable volumes. The NASA-MSFC Phase III Science and Applications Manned Space Platform (SAMSP) was evaluated during Part 1 for deployable transfer tunnels, habitat/experiment modules, and an Orbital Transfer Vehicle (OTV) hangar. A similar concept which could also benefit is

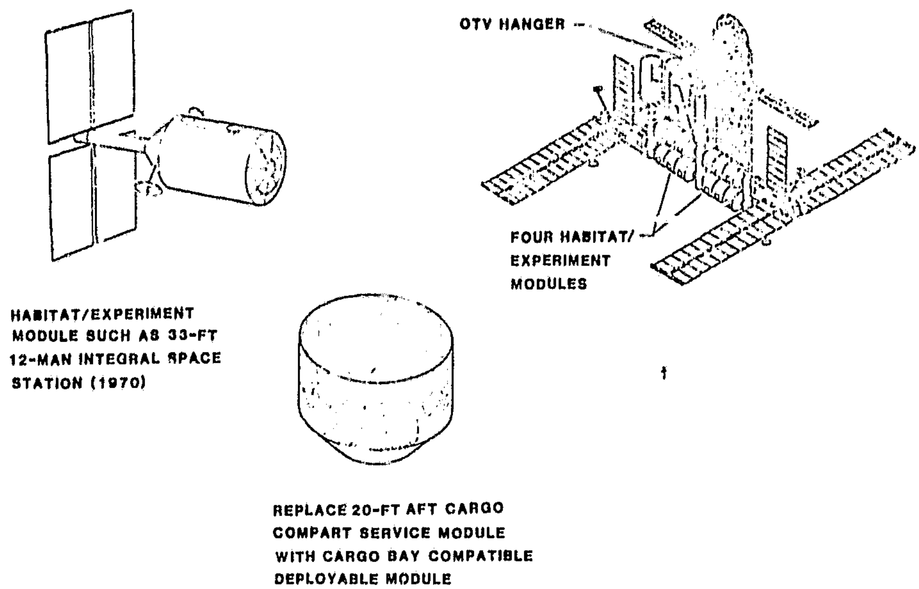

FIGURE 11
POTENTIAL MISSIONS FOR DEPLOYABLE VOLUMES

the Space Operations Center (SOC). Two other potential missions for the habitat are illustrated. One is a 20-ft diameter module which could be transported to orbit in an aft cargo compartment attached to the base of the Shuttle external tank. This module could be applied as either a service module or a crew habitability module. Use of the deployable volume concept would allow a module of this diameter to be easily packaged in the Shuttle Orbiter cargo bay. A more substantial mission challenge would be a very large Space Station module, such as represented by the 10m diameter 12-man Integral Space Station (ISS) habitat/experiment module studied in the early 1970's. This ISS module is very large, with about 1050 m^3 pressurized volume, and four floors for crew and mission accommodation. Being significantly larger than the Phase III SAMSP (about 450 m^3 habitat/experiment volume), the ISS module is representative of a large volume which demonstrates the capabilities of the deployable volume concept to accomplish things using the Space Shuttle which could not otherwise be accomplished. Representative OTV design concepts considered while evolving the deployable hangar included the Centaur G, Centaur G', and a reusable OTV concept from SOC hangar studies.

Several types of deployable volumes were considered in the concept identification task. The most promising concept for manned habitat and OTV hangar applications was found to be a deployable truss approach with a bladder for pressure containment and an external thermal/meteoroid blanket. A convoluted flexible concept was identified as offering potential for tunnels.

3.1 Habitat Module

The deployable volume concept evolved for the habitat module is illustrated in Figure 12. The module has a volume of about 1130 m^3 and is sufficiently large to support a 12-man habitat/experiment operation in space.

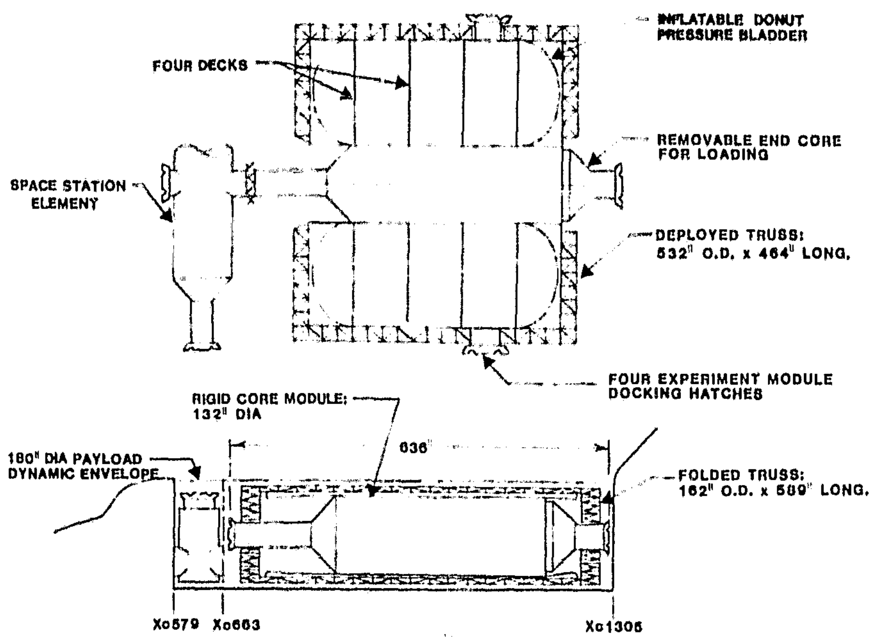

FIGURE 12
HABITAT MODULE STOWED AND DEPLOYED CONFIGURATIONS

The overall dimensions of the deployed truss structure are a cylinder approximately 13.5m diameter by 11.8m length. When stowed the truss folds into a diameter of about 4.1m and a length of about 15m. This allows adequate clearance within the 4.57m dynamic envelope of the payload bay for wraping the truss structure with the thermal/meteoroid blanket. The total length of the stowed habitat is about 16.2m, leaving space for the Orbiter docking module. One principal feature of the configuration is a rigid core module which is delivered to orbit outfitted with essential equipment for crew support and start-up operations. It also provides storage space for other structural elements to allow assembly of the basic structure in the first Shuttle delivery flight. The core module is pressurizable and has a removable aft cone with a 2m square loading hatch, allowing transfer of modularized packaged equipment on subsequent deliveries. Since these packaged articles can be delivered in a pressurized module, the buildup is almost entirely by shirtsleeve operation. The modularization of equipment packaging minimizes installation tasks. The core module also provides a rigid structure for interfacing the Shuttle cargo bay during delivery and for providing a rigid backbone for the deployed volume. The surrounding main volume area is an inflatable pressure bladder forming a cylindrical annulus around the core. The four decks provide for three levels in the large volume for crew accommodation and mounting of equipment. Four docking hatches are located around the periphery of the deployed volume, and allow interface with experiment modules and with the Shuttle for docking and resupply.

Figure 13 further illustrates buildup characteristics of the deployable habitat module where a pressurized cargo module is shown docked to the aft loading port of the core module. The modularized equipment, transfer

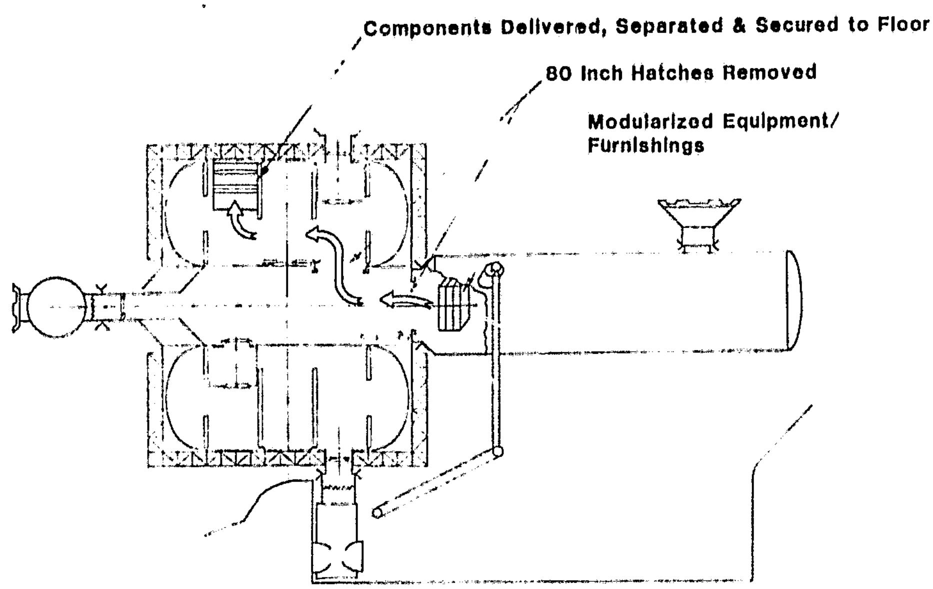

FIGURE 13
SHIRTSLEEVE TRANSFER OF MODULARIZED EQUIPMENT/FURNISHINGS

pathways, and hatch opening sizes for transfer of equipment in a minimal amount of time are also indicated. The design has been evolved to use the RMS so that no major special equipment is required. Deployment of the pressure bladder and the thermal/meteoroid blanket is integral with the truss structure, again minimizing the requirements for EVA.

The BADF truss concept was selected for use with the deployable volumes. It provides the capability for a tailored length change during deployment to match that of the pressure bladder, facilitating their integration. Figure 14 illustrates the deployed truss dimensions, and Figure 15 shows the deployment approach. The truss design uses graphite/epoxy struts. Figure 16 shows the deployable deck design, consisting of four pie-shaped sections of BADF truss. A 15 cm grid pattern of nodes, each with an attach socket, provides for equipment mounting. The pressure bladder consists of a 30-ply Kevlar-49 fabric structural layer, an inner laminated layer for atmospheric containment and flame barrier, and an outer scuff layer. The thermal/meteoroid blanket is multilayer insulation derived from the Spacelab design. Figure 17 shows the pleating scheme used to allow simultaneous truss and softgoods deployment. On the end caps the blanket is pleated radially, attached at the outer diameter and rolled around the central core at the inner diameter. As the truss deploys the blankets unwrap and expand to cover the end structure.

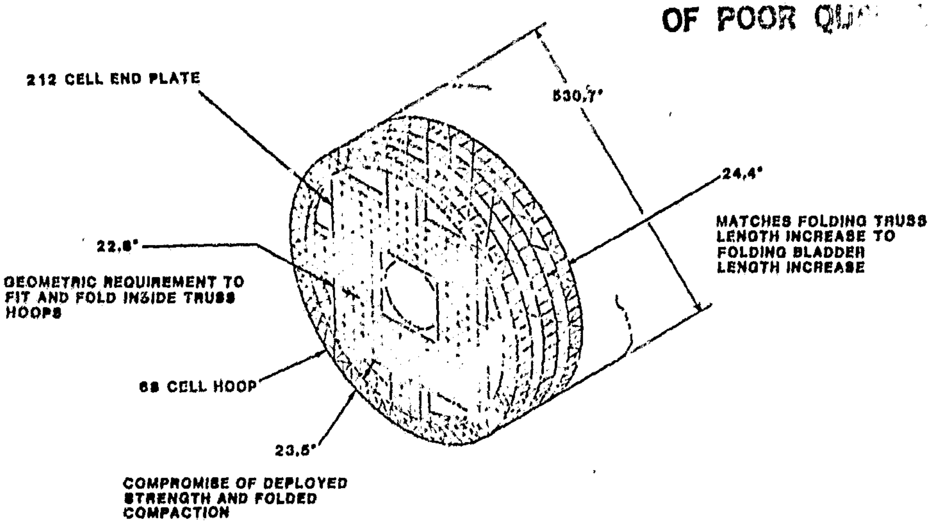

FIGURE 14
HABITAT DEPLOYABLE TRUSS STRUCTURAL CONFIGURATION

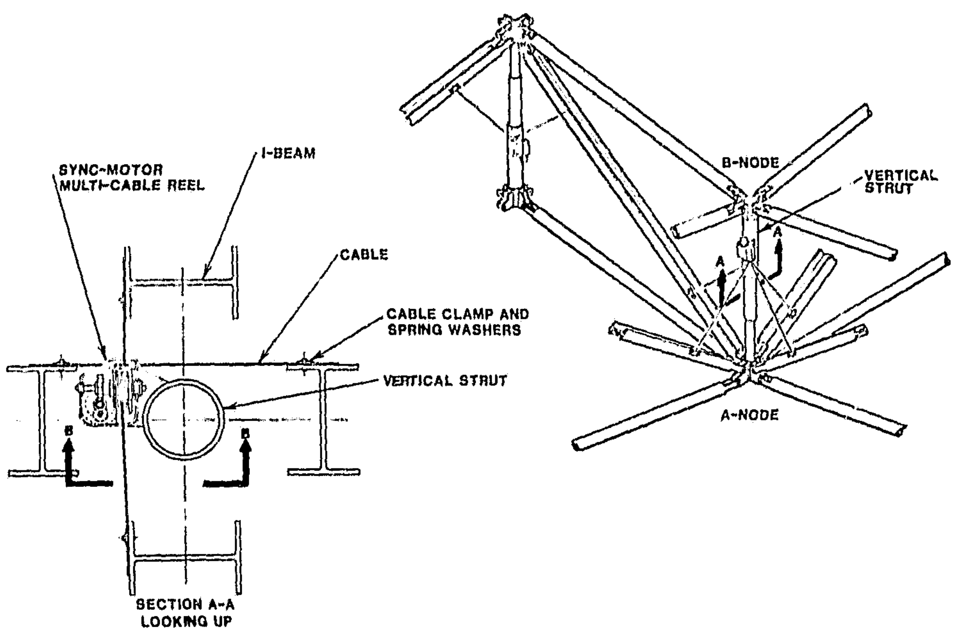

FIGURE 15
MULTIPLE MOTOR/CABLE REEL CONCEPT FOR DEPLOYING LARGE BADF TRUSS

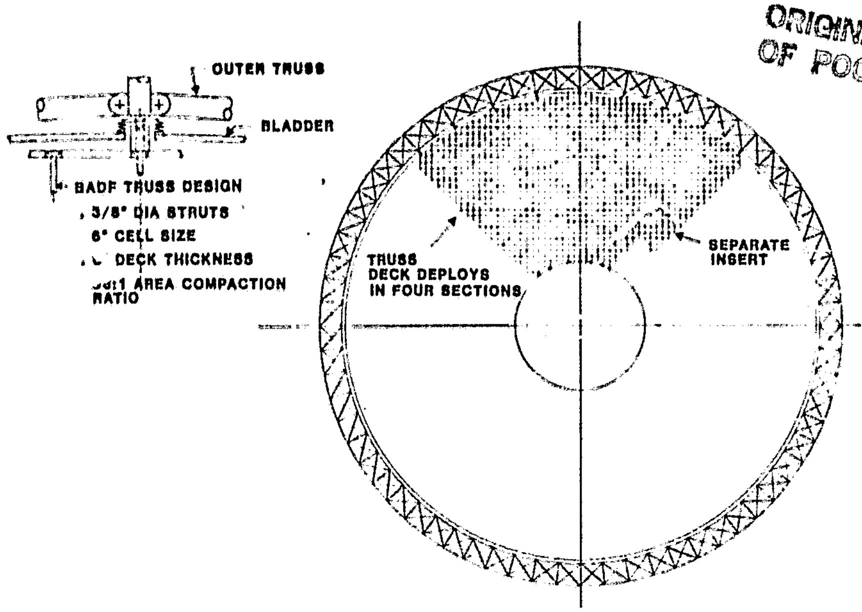

FIGURE 16
DEPLOYABLE DECK DESIGN FOR HABITAT MODULE

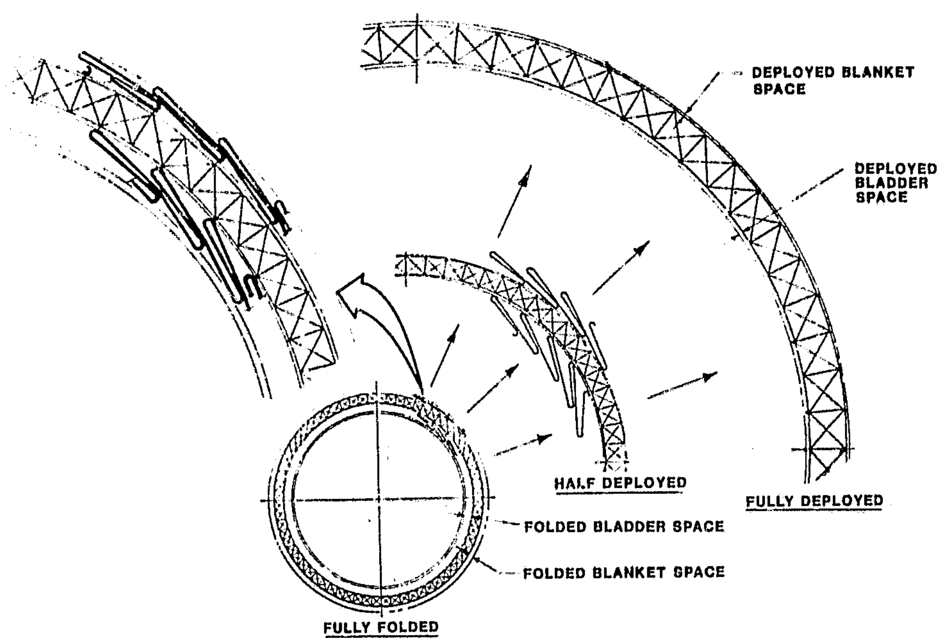

FIGURE 17
PERIFERAL EXTERNAL BLANKET AND BLADDER FOLDING/DEPLOYING

3.2 OTV Hangar

Figure 18 illustrates the OTV hangar concept. The hangar opens in a clam shell fashion to accommodate the OTV. The overall dimensions of the hangar truss structure are 23.1m length by 10.1m diameter. A rigid core is

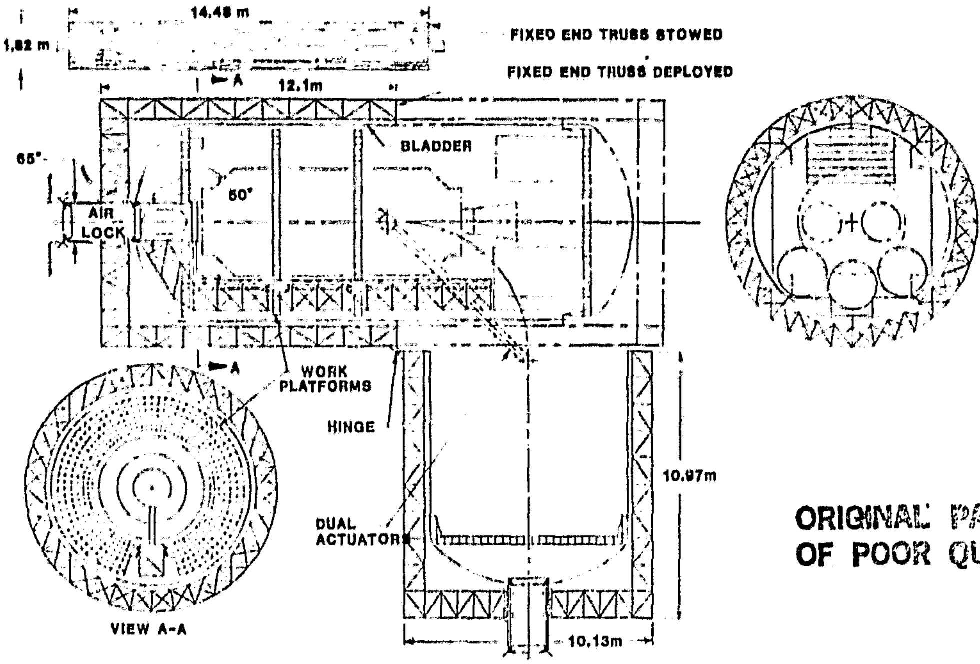

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FIGURE 18
OTV HANGAR STOWED & DEPLOYED CONFIGURATIONS

provided in the hangar concept similar to the habitat. The airlock structure, which docks into the Space Station, is connected to a tunnel structure which, in turn, mates an adapter which docks with the OTV. A truss beam, which structurally interfaces the tunnel, provides a support for ingress and egress of the OTV. Moveable work platforms are also supported off the truss beam. The work platform floors are also constructed of deployable structure and stored inside the folded volume. The folded dimensions of the hangar forward truss cylinder are 14.5m length by 1.8m diameter, and thus occupies only a small portion of the cargo bay. The forward section of the clam shell and the hinged aft section of the clam shell are stored in the cargo bay as separate cylinders. The OTV hangar may be operated as a pressurized or unpressurized version. The pressurized version with the bladder installed is illustrated in the figure, showing the bladder interface with the central core structure in the airlock area. Each bladder half is provided with a support ring and seal at the clamshell opening on the forward and aft sections. The folded configuration of the seal ring is shown stored on the inside of the folded truss structure. The OTV configuration sketched in the figure is representative of a projected version of a reuseable OTV, and is one of the larger sizes expected to be used with the hangar. In the aft portion of the clam shell storage space is provided for such items as spare ballutes or engines. A platform for storage is also indicated. A second airlock is installed in the aft clam shell, which is necessary for an alternate egress path when the hangar is used in its pressurized version. Similar to the deployable habitat, the deployable hangar has the bladder and the external thermal/meteoroid insulation blankets preattached. These deploy with the

structure. However, subsequent to deployment, RMS operation is necessary to install the airlocks on both the forward and aft ends. A combination of RMS and EVA operation is also required to unfold and install the bladder seal ring structure. The launch storage concept in the Shuttle cargo bay makes use of a core canister internal to cylindrical truss structure, similar to that used with the deployble habitat. The canister diameter is approximately 1.3m. Part of its structure is the docking tunnel, and this diameter is continued through the entire length of the truss. End plates are provided to support the canister during launch, providing a rigid backbone for launch loads. Stored inside the canister are the folded work platforms illustrated by the small circle inside the canister in the figure, and the folded rail support beams. A rigid docking ring guide is also stored inside the canister. It should be possible to deliver and erect the hangar in a single Shuttle flight.

Figure 19 illustrates the basic approach for OTV ingress and egress. Three important characteristics of that system are shown in the figure. First, the circular, cylindrical hangar pivots open like a clamshell providing

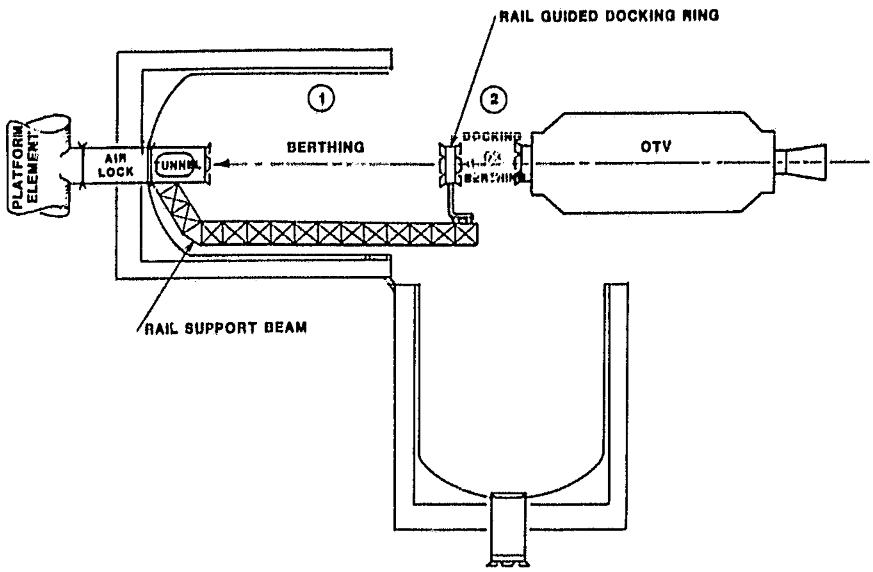

FIGURE 19
CONCEPT FOR OTV INGRESS/EGRESS

a large opening for the OTV. Second, internal hard structure in the hangar provides a firm mounting for the OTV and consists of a central core tunnel for the docking adapter and a deployed truss beam which incorporates guide rails. The third element is the docking interface, illustrated here as a rail guided docking ring. It is shown in use with the reusable OTV, which has a docking ring on the forward end. The OTV may either be brought in the proximity of the hangar and then flown into the docking ring or berthed into the docking ring using the RMS. After docking is accomplished the rail guided docking ring is translated with the OTV into the hangar and hard docked into the tunnel. As appropriate, additional supports may be made by the dolly such as an extension of the dolly under the OTV with arms to pick up the trunnion mounts already on the OTV for Shuttle interface. The rail guided docking ring is mission specific hardware and would be suitable only for the situation

indicated where the OTV has a docking adapter on the front. Other OTV vehicles such as the Centaur have a docking cradle on the aft end. The adapter ring would then be configured to interface the OTV with a structure similar to the cradle which would, in turn, dock into the hangar tunnel for firm support. For suitations where payload mating with the front of the OTV is desired, the docking ring would have a configuration which interfaces directly with the trunnions on the OTV or with an adapter situated on the aft end of the OTV allowing free space for payload mating. By extending the rail support beam further from the base of the hangar, through incorporation of an extension mechanism, other options would become available for interfacing with the OTV.

3.3 Environmental Protection

The basic deployable truss structure concept with a bladder on the inside and a thermal/meteoroid blanket on the outside inherently provides excellent meteoroid and debris protection. For the habitat module a probability of no meteoroid penetration of 0.998 for 10 years is provided. A 3.25 cm debris fragment will be stopped, yielding, based on the 1978 debris model, a probability of no debris penetration of 0.95 for 10 years. With the addition of radiators to the exterior of the habitat module, the area shielded increases in debris protection to a probability of 0.975 for no penetration for 10 years. The basic design of the habitat also provides radiation shielding of about 0.7 gm/cm^2 which is suitable low inclination LEO missions for a crew rotation period of up to 180 days. It is feasible to add additional shielding if more severe missions are required.

3.4 Deployable Volume Conclusions

1. A rigid central core concept has been developed which minimizes EVA requirements during buildup. In addition it provides a rigid backbone for interface with the Orbiter during launch. For the habitat the concept utilizes a central core module which is pressurizable and which interfaces with a cargo module for shirtsleeve delivery of additional modularized equipment.

2. A large deployable habitat module can be delivered and erected in one Shuttle flight, and completely outfitted with an additional 1-2 Shuttle flights. The 13.5m diameter habitat would accommodate up to twelve men.

3. A 10.1m diameter by 23.1m long deployable OTV hangar can be delivered and assembled in one Shuttle flight. This hangar is suitable for pressurized or unpressurized OTV operations and will accommodate both near term earth-based OTV designs as well as future reusable space-based concepts.

4. The BADF structure provides best overall compatibility with deployable volumes, and permits integral attachment and deployment of the external thermal/meteoroid blanket and the pressure bladder.

5. Excellent micrometeoroid and debris protection is inherently provided by the blanket/truss/bladder configuration, and shielding from space radiation is adequate for low inclination LEO missions for 180-day crew rotation.